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ANTENNA PATTERN CONTROL USING IMPEDANCE SURFACES

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March 16, 1992 – September 15, 1992

by
Constantine A. Balanis and Kefeng Liu

Prepared by

Telecommunications Research Center
College of Engineering and Applied Science
Arizona State University
Tempe, AZ 85287-7206

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ABSTRACT

This is a semiannual progress report for the *Antenna Pattern Control Using Impedance Surfaces* research grant. This report covers the research period from March 16, 1992 to September 15, 1992.

During this research period, we have effectively transferred existing computer codes from CRAY supercomputer to work station based systems. The work station based version of our code preserved the accuracy of the numerical computations while giving a much better turn-around time than the CRAY supercomputer. Such a task relieved us from the heavy dependence of the supercomputer account budget and made codes developed in this research project more feasible for applications.

The analysis of pyramidal horns with impedance surfaces was our major focus during this research period. Three different modeling algorithms in analyzing lossy impedance surfaces were investigated and compared with measured data. Through this investigation, we discovered that a hybrid Fourier transform technique, which uses the eigen mode in the stepped waveguide section and the Fourier transformed field distributions across the stepped discontinuities for lossy impedances coating, gives a better accuracy in analyzing lossy coatings. After a further refinement of the present technique, we will perform an accurate radiation pattern synthesis in the coming reporting period.

I. INTRODUCTION

A. Code Generalization

One of the major tasks of this research project is to make computer codes we developed available to our contractors. In this research period, we have devoted considerable amount of time in optimizing the existing codes to make them more feasible for general applications.

Due to the large electrical areas ($100\lambda^2$ to $200\lambda^2$) involved in the electromagnetic problem region, the requirements of computational power may present a challenge to even the fastest supercomputer in the world. Previously, we depended heavily on the CRAY Y-MP at the NCSA, CRAY Y-MP in NASA Langley Research Center, and CRAY X-MP at Arizona State University to perform our computations. Due to limited supercomputer resources outside ASU, the ASU X-MP/116se had been the primary computing resource for this research project. Since the out-of-core memory version of the code requires about 2 to 10 hours of CRAY X-MP CPU and around 1 Gbyte of hard disk space to swap the impedance matrix, we frequently encountered problems in the time queue, memory queue, and disk space in the ASU CRAY system. Many times, we had to wait for a week to get the job into the running module, and three days later the job was aborted because there was not enough disk space for matrix swapping. This had been a very frustrating situation for the past two years.

A high computational requirement and an expansive supercomputer account budget could greatly limit applications of formulations and computer codes developed in this research project. We have been trying to resolve this problem for the past two years. In the early stage of this research period, ASU announced its decision to remove the CRAY X-MP/116se from its campus. Therefore, this problem became even more pressing for us. Alternative computational resources had to be found for this research project. Two benchmarks were developed to run on a variety of computers such as CONVEX C-220 main-frame supercomputer, Sun SPARCStation, DEC5000 Station, Iris Crimson Station, HP Apollo Stations, and IBM RS6000 Stations. The following list represents test results of the best three computer vendors:

BENCHMARK TESTING DATA

Code : Apera.f--This version uses paging feature for virtual memory in all workstations. It takes 1817 sec (single processor speed without paging) in Y-MP8/5128 in NASA Langley.

	Performance		
Model	CPU (in seconds)	Optimization	Fortran Version
RS-6000 series			
350	9949	NO	New
	4052	YES	New
	4355	YES	OLD
530H	12233	NO	NEW
560	3654	YES	OLD
HP-9000 series			
730 (32M module)	43885	YES	N/A
730 (64M module)	4181	YES	N/A
IRIS			

Crimson	5349	YES (Old Unix)	N/A
	5274	YES (New Unix)	N/A

Code : Apero.f--This is an out-of core version close to the full scale computation needed for my application. It takes 3196 sec in X-MP/116se in ASU (using BUFFER I/O for out-of core matrix swappings).

Performance

Model	CPU (in seconds)	Optimization	Fortran Version
RS-6000 series			
350 (s. p.)	9337	YES	NEW (Wrong Solu.)
(d. p.)	6449	YES	NEW (Right Solu.)
560 (s. p.)	8146	YES(old Unix)	OLD (Wrong Solu.)
HP-9000 series			
730 (s. p.)	>80 hours	YES	N/A
IRIS			
Crimson	>90 hours	YES	N/A

We are more concerned about the performance of the out-of-core benchmark since most analysis has to be performed using matrix swapping. Therefore, the IBM RISC-6000 stations out-performs any other machine. The computational power of the IBM workstations represents about one-third to half the power of the CRAY supercomputer.

After some modifications, we have made the existing computer codes portable among workstations with UNIX system. Currently, we can use an IBM RISC6000-350 workstation to perform our analysis.

B. Analysis of Lossy Material Coatings

In previous reporting periods, we have presented the stepped-waveguide model for analyzing the lossy impedance coating on the interior surfaces of the horn transition. Figure 1 represents the stepped waveguide model for the analysis of a partially coated horn transition. Unlike the perfectly conducting part of the horn transition, the stepped-waveguide model for the lossy material coated section of the horn transition exhibits a much more complicated boundary conditions at the stepped discontinuity.

Figure 2 shows three types of interfaces encountered in the stepped model. The difficulties involved in an accurate analysis of the lossy coating can be discussed in two parts. First of all, to avoid a high gain loss, the thickness of lossy material coating should be relatively thin compared to the cross-sectional sizes of the horn transition. Therefore, to effectively control field taperings, the coated lossy material should have a relatively high dielectric constant and/or a high permeability[1, 2, 3]. The analysis of the field taperings can be carried out by using eigen modes given by a partially filled waveguide techniques[4]. An accurate expansion of the field distributions controlled by a small part of the discontinuity at the edges of the cross section requires many eigen modes. This could present a numerical difficulty. Secondly, the stepped waveguide model artificially creates media discontinuities at the stepped junction which could act as a false control on the field distributions.

To investigate these problem, three different techniques in modeling the coating discontinuity were studied in this research period:

- Solving the stepped discontinuity exactly as shown in Figure 2. This technique is theoretically exact boundary condition solution, if it were a real stepped discontinuity at the interface. However, due to the incompleteness of eigen modes and the artificially created material discontinuities, this method does not work very well. The predicted E-plane pattern presented in the previous report showed some discrepancies even in the main lobe of the pattern.

- Approximating the material interface by assuming a continuous material transition(there is no material-air interface as shown in Figure 2 for the stepped discontinuity). By this assumption, the eigen values of eigen modes on both sides of the stepped discontinuity are assumed to be their original values. This method might be able to average out some of the artificial discontinuities on the interface. As a result, the computed patterns have demonstrated a better agreement with measured data.

- Hybrid Fourier transform method. This method applies a Fourier transform to expand field distributions of eigen modes on both sides of the stepped discontinuity. By testing the transformed field distributions with different weighting functions on the discontinuity, the full-wave coefficients are related. Once the discontinuity is resolved, the field distributions are transformed back to the eigen mode expansion in the waveguide section to account for the propagation factor. To our surprise, this method gave us the best agreement among the three. We do not yet have a sound explanation for this result. However, it looks like this method averages out the error more effectively than the other two.

A detailed description of the formulations and algorithms for the analysis of the stepped-waveguide model for lossy material coated horn transition will be presented in the next reporting period.

II. RESULTS AND DISCUSSIONS

Based on the hybrid Fourier transform stepped discontinuity algorithm, numerical analyses were carried out to predict the E-plane radiation patterns for the 20-dB X-band standard gain horn with 2cm, 5cm, and 10cm Northrop Nitrile lossy magnetic material coating from the radiating aperture. The Nitrile material has a measured relative permitivity of $18.75 - j0.1$ and a relative permeability of $1.55 - j1.85$ at 10 GHz. The thickness of the material is 44 mils. However, considering the tilting effect when the material is coated, the effective thickness is taken to be 44.41 mils. In figures 3 to 5, we also include the predicted pattern of the horn without a material coating (PEC wall surfaces) to demonstrate the effect of lossy material coatings on the control of antenna radiation patterns.

Figure 3 shows the comparison of the measured and predicted E-plane radiation patterns for the 20-dB X-Band standard gain horn with 2cm of the lossy magnetic coating. We observed a good agreement in the main lobe and a small discrepancy in the back regions. This demonstrates that the presented Fourier transform technique can be used to analyze the lossy coatings with a reasonably good accuracy. Figure 4 represents the E-plane patterns for the same horn with 5cm of lossy magnetic material coating. It exhibits the same agreement as that of Figure 4 except that the measured gain is a about 0.7 dB lower than predicted. Figure 5 includes the E-plane patterns for the horn with 10cm lossy magnetic coating. In the figure, we observed more discrepancies between the predicted and measured patterns. We believe that the discrepancy is caused by the inaccuracy of the stepped waveguide model in the smaller cross sectional portion of the horn transition. Efforts will be devoted to identify the major contributor of the inaccuracy so that a better weighting function can be used to model the lossy material coated transition more accurately.

We would like to mention that although the results presented in this report are not perfect, they represent the first full-wave attempt for solving a pyramidal horn antenna with lossy magnetic coatings. Once the formulation is refined, it will represent a valuable full-wave method for the analysis of horn transitions with lossy material coatings.

Two FORTRAN computer programs (**hornf.f** and **horng.f**) are transferred to NASA Langley Research Center during this report period. Both codes are portable among UNIX or UNICOS system. Program **hornf.f** was developed for a robust analysis of a pyramidal horn antenna radiating in free space. Formulations and techniques used to analyze this problem are summarized in[5]. Most of the materials were also presented in the previous reports. We fixed few of the programming bugs in this reporting period. Therefore, the presented version of **hornf.f** will provide even more accurate predictions of the pyramidal horn antennas than those presented in previous reports. The improved accuracy can be better observed when electrically large pyramidal horns are analyzed. Program **horng.f** was developed for the analysis of a pyramidal horn antenna mounted on an infinite ground plane. Since the outside surfaces of the pyramidal horn are shielded by the ground plane, only the radiating aperture needs to be represented by a magnetic field integral equation. Field formulations used to analyze this problem are similar to those of Wriedt's in [6]. This program provides an excellent accuracy in predicting the electromagnetic field radiation into half-space. We will include the rest of the computer codes developed for this research program in next reporting period when we finish refining some of the existing algorithms.

III. FUTURE WORK

In the coming research period, we will further investigate the inaccuracy in modeling lossy coating horn transition so that more accurate predictions can be made. Only an accurate analysis of the lossy coating will allow us to perform a viable synthesis of the antenna pattern.

IV. PUBLICATIONS

During this reporting period, the paper entitled "Integral equation analysis of high-gain pyramidal horn antennas," pp. 592–595 in *1992 IEEE APS/URSI/NEM Joint Symposium Digest*, Chicago, Illinois was awarded the second prize winner in the PhD student paper category.

We have just received the reviews of the paper entitled "Analysis of pyramidal horn antennas using moment methods, " by Kefeng Liu, Constantine A. Balanis, Craig R. Birtcher, and George C. Barber, submitted for publication in the *IEEE Trans. on Antennas and Propogation. The reviewers have suggested some revisions before acceptance of the paper.*

References

[1] C. S. Lee, S. W. Lee, and D. W. Justice, "A simple circular-polarized antenna: Circular waveguide horn coated with lossy magnetic material," *IEEE Trans. Antennas Propagat.*, vol. AP-36, pp. 297–299, Feb. 1988.

[2] J. J. H. Wang, V. K. Tripp, and J. E. Tehan, "The magnetically coated conducting surface as a dual conductor and its application to antennas and microwaves," *IEEE Trans. Antennas Propagat.*, vol. AP-38, pp. 1069–1077, July 1990.

[3] J. J. H. Wang, V. K. Tripp, and R. P. Zimmer, "Magnetically coated horn for low sidelobes and low cross-polarization," *IEE Proceedings*, vol. 136, pp. 132–138, Apr. 1989.

[4] C. A. Balanis, *Advanced Engineering Electromagnetics*. Wiley, 1989.

[5] K. Liu, C. A. Balanis, and G. C. Barber, "Analysis of pyramidal horn antennas using moment methods," *IEEE Trans. Antennas Propagat.*, 1992. to be published.

[6] T. Wriedt, K. H. Wolff, F. Arndt, and U. Tucholke, "Rigorous hybrid field theoretic design of stepped rectangular waveguide mode converters including the horn transitions into half-space," *IEEE Trans. Antennas Propagat.*, vol. AP-37, pp. 780–790, June 1989.

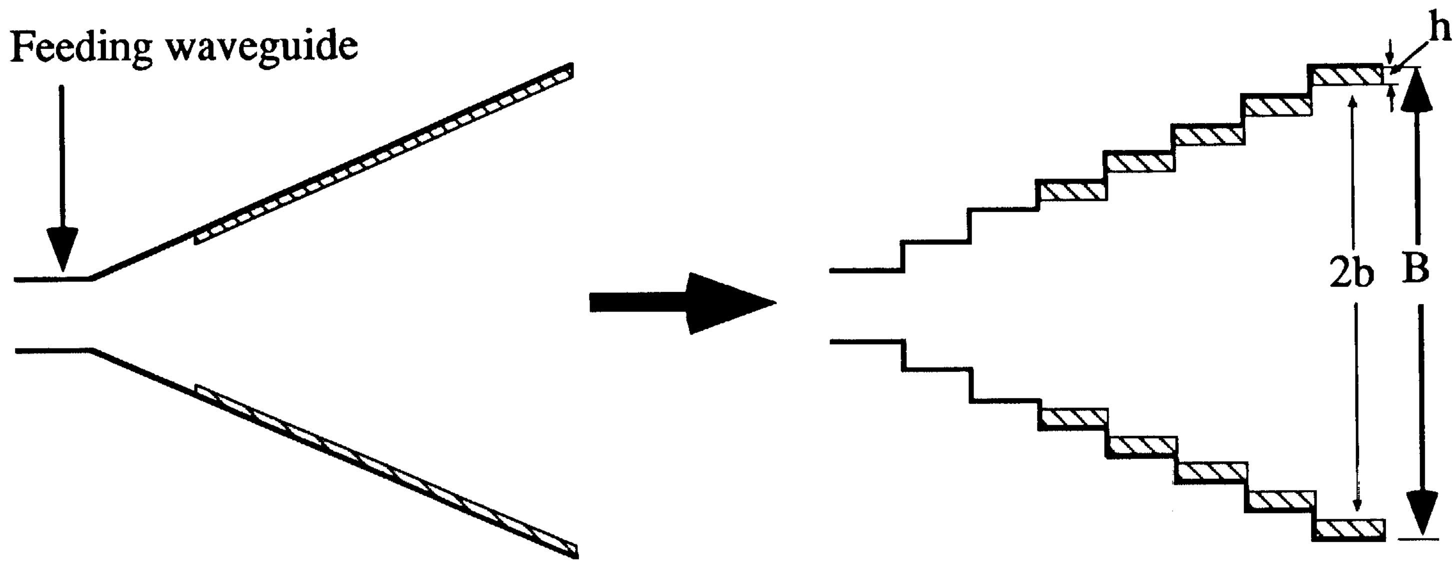

Figure 1. Stepped-waveguide model for a horn transition with partially coated impedance surfaces.

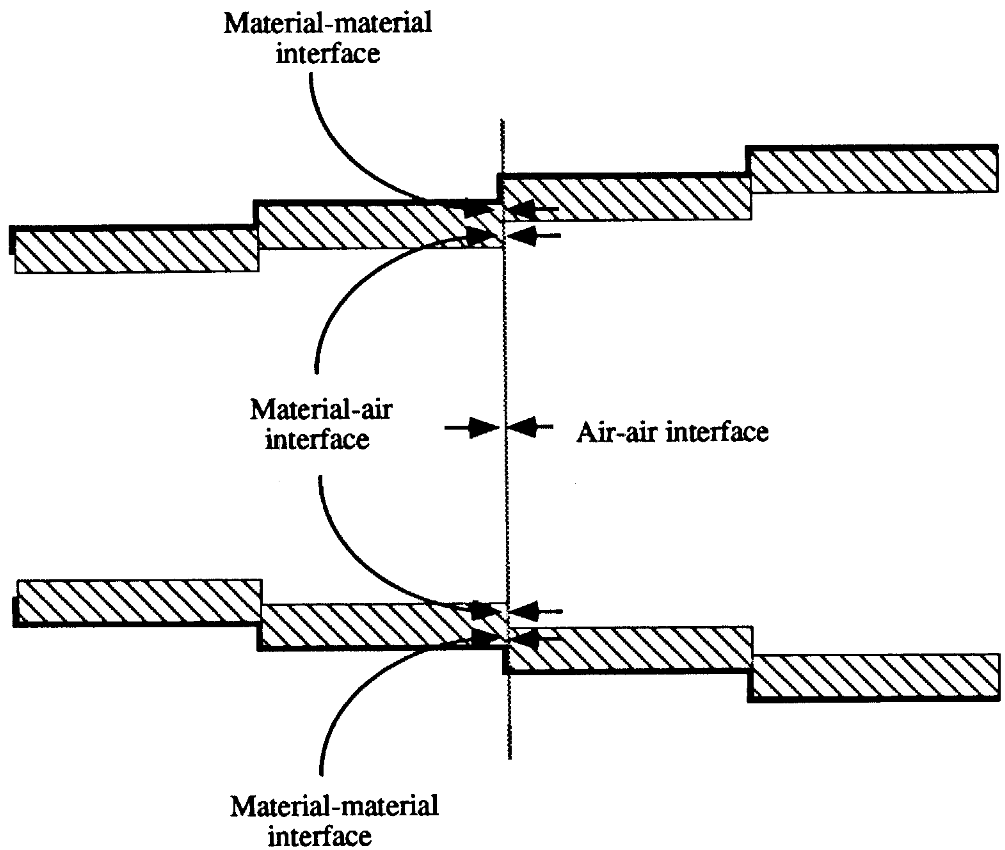

Figure 2. Stepped discontinuity in a stepped-waveguide model of the material coated horn transition.

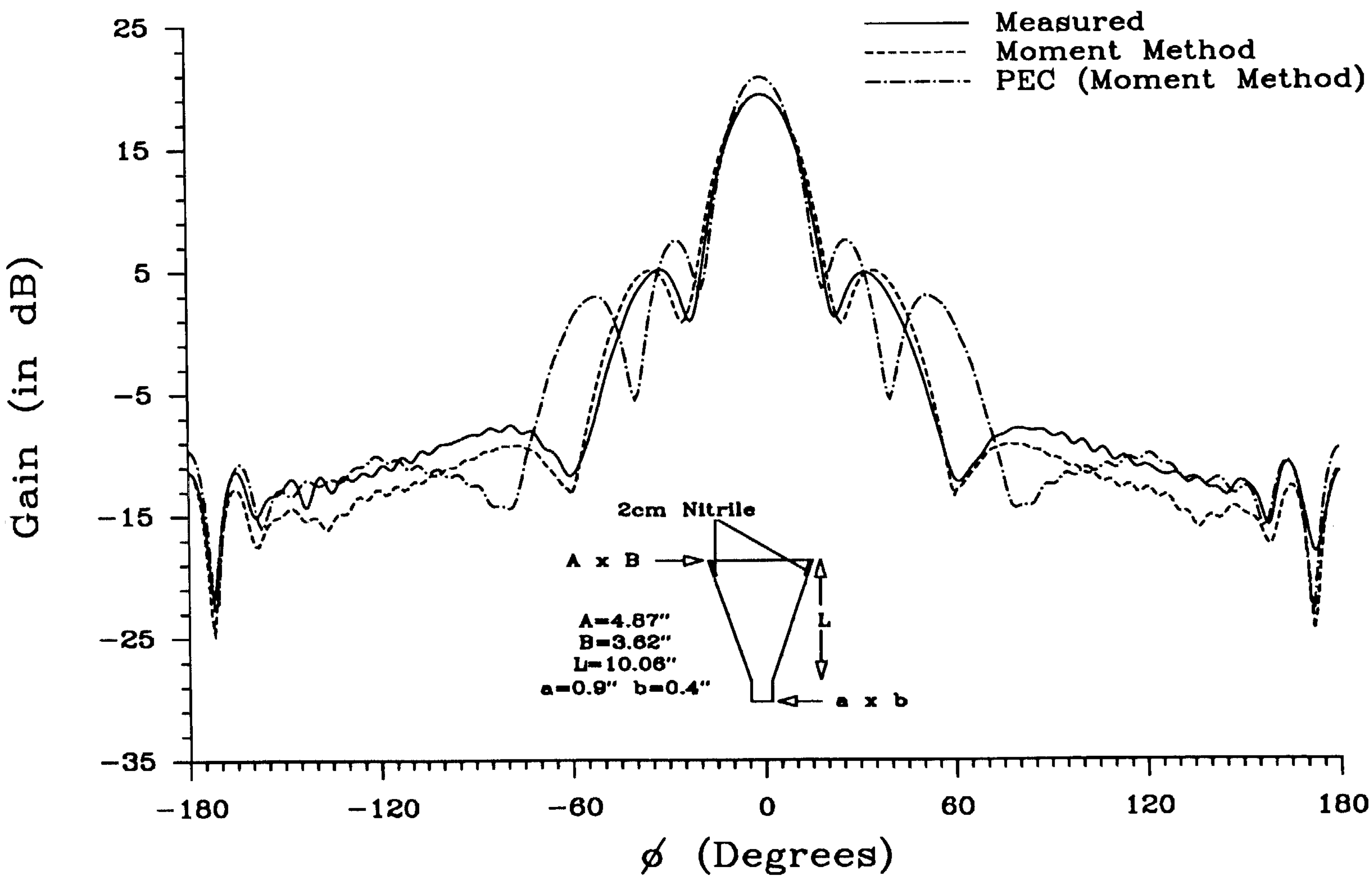

Figure 3. Comparison of E–plane patterns for standard gain horn horn at 10 GHz with 2cm of lossy Nitrile material coating.

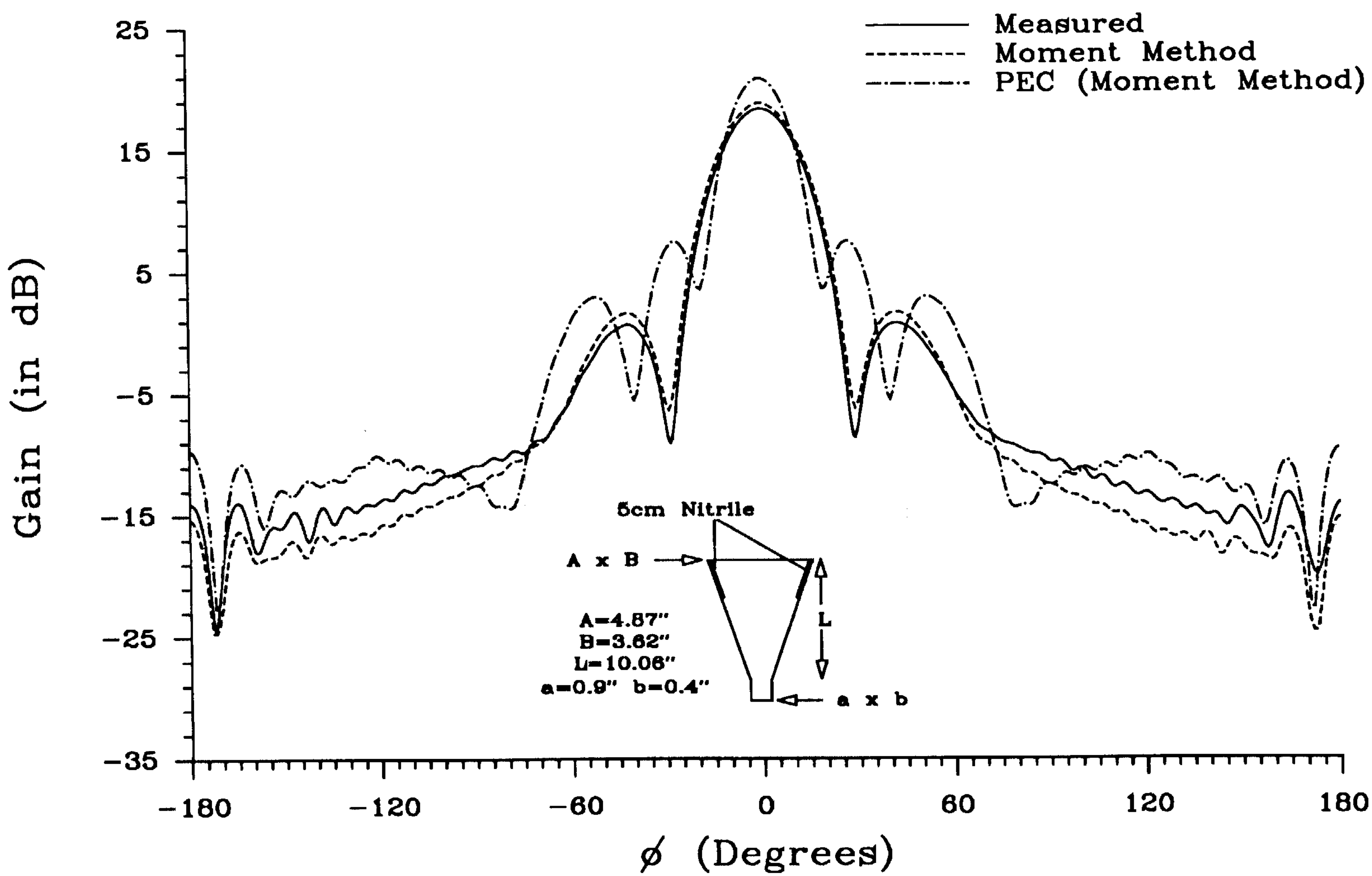

Figure 4. Comparison of E-plane patterns for standard gain horn horn at 10 GHz with 5cm of lossy Nitrile material coating.

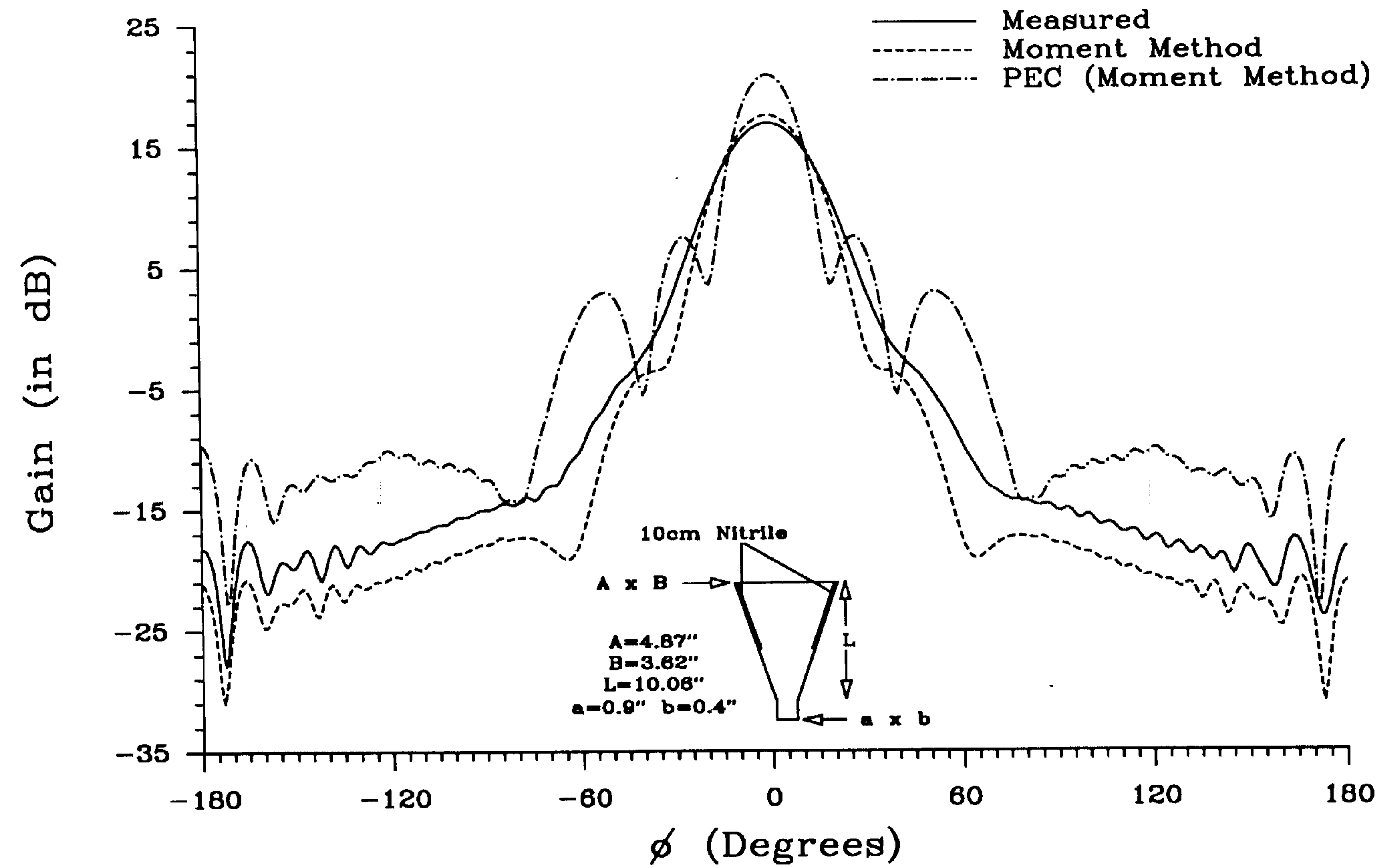

Figure 5. Comparison of E-plane patterns for standard gain horn horn at 10 GHz with 10cm of lossy Nitrile material coating.